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A robust estimation of the effects of Motorcycle Autonomous Emergency Braking (MAEB) based on in-depth crashes in Australia

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ABSTRACT

Objective. Autonomous emergency braking (AEB) is a safety system that detects imminent forward collisions and reacts by slowing down the host vehicle without any action from the driver. AEB effectiveness in avoiding and mitigating real world crashes has recently been demonstrated. Research suggests that a translation of AEB to powered two wheelers could also be beneficial. Previous studies have estimated the effects of a motorcycle AEB system (MAEB) via computer simulations. While effects of MAEB were computed for motorcycle crashes derived from in-depth crash investigation, there may be some inaccuracies due to limitations of post-crash investigation (e.g. inaccuracies in pre-impact velocity of the motorcycle). Furthermore, ideal MAEB technology was assumed, which may lead to overestimation of the benefits. This study sought to evaluate the sensitivity of the simulations to variations in reconstructed crash cases and the capacity of the MAEB system, in order to provide a more robust estimation of MAEB effects.

Methods. First, a comprehensive classification of accidents was used to identify scenarios in which MAEB was likely to apply, and representative crash cases from those available for this study were populated for each crash scenario. Second, 100 variant cases were generated by randomly varying a set of simulation parameters with given normal distributions around the baseline values. Variants reflected uncertainties in the original data. Third, the effects of MAEB were estimated in terms of the difference in the impact speed of the host motorcycle with and without the system via computer simulations of each variant case. Simulations were repeated assuming both an idealized and a realistic MAEB system. For each crash case, the results in the baseline case and in the variants were compared.

A total of 36 crash cases representing 11 common crash scenarios were selected from three Australian in-depth datasets: 12 cases from New South Wales, 13 cases from Victoria, and 11 cases from South Australia.

Results. The reduction in impact speed elicited by MAEB in the baseline cases ranged from 2.8 km/h to 10.0 km/h in the baseline cases. The baseline cases over- or underestimated the mean impact speed reduction of the variant cases by up to 20%. Constraints imposed by simulating more realistic capabilities for an MAEB system produced a decrease in the estimated impact speed reduction of up to 14% (mean 5%) compared to an idealised system.

Conclusions. The small difference between the baseline and variant case results demonstrate that the potential effects of MAEB computed from the cases described in in-depth crash reports are typically a good approximation, despite limitations of post-crash investigation. Furthermore, given that MAEB intervenes very close to the point of impact, limitations of the currently available technologies were not found to have a dramatic influence on the effects of the system.

INTRODUCTION

Autonomous emergency braking (AEB) is an advanced assistance system designed to identify imminent collisions and to react by automatically activating the brakes. Since its first introduction on passenger cars in 2006, the penetration of AEB in the general vehicle fleet has recently allowed for assessment of the effectiveness of this system in real world crash scenarios ([Fildes et al., 2015](#)). In the future AEB is likely to become a standard feature for passenger cars, especially given its inclusion in the list of advanced systems for passenger cars considered and promoted by Euro NCAP and ANCAP.

Given the documented effectiveness for cars, an exploration of possible translations of AEB to powered two wheelers is reasonable. However, the introduction of a motorcycle AEB (MAEB) is likely to be challenging. First, from a technical point of view, passenger vehicle AEB systems would need to be redesigned to be more compact and to operate effectively on two wheeled vehicles with a low mass. The lower cost of two wheeled vehicles would also necessitate that any accompanying AEB system be less expensive. Furthermore, the potential effects of automatic braking actions on the stability of a single track vehicle need to be accounted for. Secondly, users' acceptability is expected to be a barrier to the introduction of such a system ([Beanland et al., 2013](#)). A motivation for the development of MAEB may be provided by a demonstration of safety benefits for the users. The initial step in an investigation of the safety potential of MAEB is an evaluation of its effects in the case of a collision.

In the literature, basic AEB concepts for motorcycle application were firstly proposed and evaluated in 2009 by Roll et al. ([Roll, Hoffmann, & Konig, 2009](#)). In that study, German crash cases extracted from the DEKRA database were used to evaluate the impact speed reduction that advanced braking assistance would have produced using a case-by-case approach. The authors considered three possible technologies for braking assistance: integral braking, antilock braking, and automatic pre-charging of the brake hydraulics. The latter technology aimed to reduce delays of manual braking and deployed when an imminent collision was detected. In the same year the consortium of the EC funded PISa (acronym of 'Powered two wheeler Integrated Safety') project presented an evaluation of the potential benefits of MAEB over a set of real-world motorcycle crashes (60 cases from Germany and UK) ([Savino, Pierini, Rizzi, & Frampton, 2013](#)). The estimate was based on 2D

simulations reproducing vehicles trajectories in the last two to three seconds before actual collisions. The precision was limited by the level of detail and reliability of the information included in the crash data reports. More recently, the same method was used in a multinational study with a larger dataset ([Savino et al., 2014](#)). In that study, the authors used computer based crash reconstructions to inform the 2D simulations used for the evaluation, thus improving the level of confidence of the results. However, a degree of uncertainty was still inevitable. In another study, detailed 3D simulations were used to perform a sensitivity analysis of the effects of MAEB. Ten fatal rear-end crashes were considered. The study highlighted that the effects of the system could be influenced by variations in the estimated initial positions, speeds or actions performed by the rider. It is understood that previous results on the potential effects of MAEB on real world crash cases may have suffered from low representativeness due to uncertainties in the initial conditions used in the simulations. In this regard, the first aim of this paper was to assess whether the effects of MAEB evaluated by simulating a certain crash case with given initial conditions can represent the MAEB effects for the range of uncertainty in the initial conditions.

Another possible source of error in the evaluation of MAEB effects in previous works was the type of obstacle detection system considered in the simulations. In this regard, the second aim of this paper was to compare the effects of MAEB obtained assuming an ideal obstacle detection system to the effects obtained when taking the limitations of a real system into account.

DATASETS

This study used data contained in the in-depth reports of real world crash cases from three Australian crash investigation studies. These independent datasets are briefly described in the following paragraphs.

The Monash University Accident Research Centre (MUARC) dataset contained records for 123 in-depth investigations of motorcycle crashes collected between 2012 and 2014 in Victoria as part of a case-control study (MICIMS). Riders were approached after being admitted to a major trauma hospital. Inclusion criteria were: rider aged over 18 years old, and crash occurred between 6am and midnight within 150 km radius of Melbourne. A research nurse conducted a questionnaire-based interview with the rider, followed by review of medical records. A crash investigation was conducted following the interview, including inspection of the motorcycle and crash site by a trained crash investigator and experienced motorcyclist. Information from attending police was requested for a small proportion of cases.

The Neuroscience Research Australia (NeuRA) dataset contains records for 100 in-depth investigations of motorcycle crashes collected between 2012 and 2014 in NSW. Cases were a convenience sample of riders admitted to a major trauma hospital following a crash within a 200 km radius of Sydney. Recruitment occurred sporadically based on availability of research nurses and notification of eligible participants by staff in the trauma wards. The NeuRA crash investigation program uses an ANCIS (Australian National Crash In-depth Study) like retrospective method. This method involves in-depth interviews with the rider, detailed review of medical records, and inspection of the crash scene, vehicles and protective equipment involved within two weeks of the crash. Police data was also collected for cases where participants gave permission to access these records (approximately 30% of cases). Investigation data was compiled into crash summaries and reviewed by a multi-disciplinary panel consisting of mechanical engineers, traffic engineers, motorcycle safety specialists,

behavioural scientists, trauma clinicians and crash investigation experts. Crash circumstances were largely based on witness statements and verified by evidence within the data collected and agreed to by the expert panel. The Centre for Automotive Safety Research (CASR) at the University of Adelaide operates an ongoing in-depth at-scene crash investigation program, which has been running in its current form since 2006. CASR's investigation team is notified by an automatic paging service every time the South Australian Ambulance Service is called to a crash. The team immediately attends the scene of the crash to begin its investigation. The criteria for investigation is any type of road crash within a 100 km radius of metropolitan Adelaide, which results in at least one crash participant being transported to hospital. The information collected for each crash includes: photographs of the scene immediately post-crash, photographs and examination of crash-involved vehicles, interviews with witnesses, interviews with police, an engineering survey of the crash site, drive-through videos of the crash site, police reports, Coroner's reports for a fatal crash, injury data from hospitals and all other crash-related medical information, licensing histories for all drivers/riders, crash history for the crash site, crash history for the vehicles involved, a computerised reconstruction of the crash, and detailed interviews with consenting crash participants about the crash and all relevant background information. Each case is submitted to a multidisciplinary review panel to agree on factors contributing to the crash. A summary of the characteristics of the three crash datasets is given in Table 1. The details from each of these datasets are sufficient to describe the pre-crash trajectories of all vehicles involved, including the timing of any braking or avoidance manoeuvres.

METHODS

The method consisted of the following steps: i) a shortlist of crash scenarios where MAEB is potentially applicable was identified; ii) for each of those scenarios, baseline computer simulations of a set of representative crash cases were created; iii) then, variant cases were generated from each baseline simulation by randomly altering the initial conditions; iv) in each baseline and variant case, the effects of MAEB were evaluated by comparing the actual impact speed of the motorcycle with the impact speed obtained assuming the motorcycle was fitted with MAEB; v) baseline cases were also simulated assuming a MAEB system with a more realistic obstacle detection capability; vi) results were analysed both in aggregated form and grouped by crash scenarios.

Identification of the Crash Scenarios

Crash scenarios were described using the Definition for Classifying Accidents (DCA) codes adopted by VicRoads in Victoria, Australia ([VicRoads, 2008](#)). A shortlist of DCA scenarios in which MAEB is applicable was then identified considering the applicability of a reference MAEB system ([Savino, Pierini, & Baldanzini, 2012](#)). MAEB applies to crash scenarios in which the motorcycle is travelling along a straight or a curve with very large radius (i.e. when the motorcycle is fully upright or leaning with a small roll angle) and the obstacle is visible in front of the motorcycle (narrow obstacles will not trigger the system). The evaluation of the applicability of MAEB to DCA scenarios was performed by two researchers using the ratings scale shown in Table 2, while a third researcher resolved classification conflicts. The researchers involved in this phase were scientists with 10 to 20 years of experience in the field of road crash investigations and design/validation of safety systems (two of them are the authors GS and MF). In some cases that involved more than one vehicle and/or more than one possible trajectory, DCAs were split into two or more subcases.

Selection of Real-World Crash Cases

Up to six real-world cases representing each DCA identified in the previous step were selected from three in-depth crash investigation datasets: CASR ([Anderson, Doecke, Mackenzie, & Ponte, 2013](#)), MICIMS ([Day et al., 2013](#)), and NeuRA ([Brown et al., 2015](#)). Scenario descriptions were recoded for the CASR and NeuRA cases in order to match with the Victorian DCA codes. Crash cases were selected to best satisfy the following criteria: i) completeness of the information available in the crash reports; ii) level of confidence in the case reconstruction expressed by the crash investigators; iii) variability in the crash circumstances within the selected cases of each crash scenario. This shortlist of crashes represented the set of baseline cases used in the following steps. Computer simulations of the baseline cases were created according to the information available in the crash records. Collisions were simulated in a Matlab environment based on a two dimensional reconstruction of vehicle trajectories. Basic equations of motion, along with suitable coefficient of friction, were utilised to account for the trajectories (rectilinear, circular) and the effects of braking/acceleration. There was no attempt made to simulate complex interactions such as yawing motions (although such events were not noted to determine a change in the overall trajectory in any of the selected cases, as the motorcycle was always travelling along a straight).

Generation of a Distribution of Case Variants

The input parameters used in the baseline simulation (initial speed, heading, etc.) were derived from information collected through retrospective crash investigation. As such, they represent the best approximation available of the actual values. However, there is an inherent level of uncertainty due to the investigation and reconstruction process. A previous study that performed a sensitivity analysis of MAEB effects showed that the variation in MAEB effects cannot be easily predicted and typically varies case by case ([Savino, Giovannini, Baldanzini, Pierini, & Rizzi, 2013](#)). Therefore in this study the uncertainty in the pre-crash configuration was addressed by generating a reasonably large set of alternative cases (variants) with modified parameters (Monte Carlo approach). Six parameters were considered in this process with their associated standard deviations (Table 3). The modified values for these parameters were randomly generated assuming normal distributions around the baseline values. For each reference case, 100 variants were generated.

Effects of MAEB

Each baseline and variant case was simulated twice. In the second simulation, the motorcycle was assumed to be fitted with an MAEB system in order to compare the impact speed of the motorcycle with and without the system. This impact speed reduction is assumed to be related to the energy dissipated during the collision, which could be possibly related to the rider's injuries (although at present a validated model of such relationship between impact speed and rider's injuries is not known). In the simulations involving MAEB, autonomous braking was triggered as soon as an inevitable collision was detected. The full details of the brake triggering algorithm, which utilises the look up table method, are presented elsewhere ([Savino, Giovannini, Fitzharris, & Pierini, 2016](#)). Position, heading and speed for each vehicle were the inputs for the MAEB triggering algorithm. If the rider was not braking at the time of triggering, MAEB produced a deceleration of the host motorcycle of 0.3 g (30% of full braking in typical conditions on dry asphalt, where g is the acceleration of gravity). If the rider was already braking at the time of MAEB triggering, or as soon as the rider braked, MAEB controlled the braking system to achieve a deceleration of up to 0.9 g (90% of full braking). In case of cornering, the braking

deceleration was automatically reduced in order to guarantee the lateral grip according to the Kamm's circle model ([Kiencke & Nielsen, 2000](#)).

Realistic Obstacle Detection

Simulations assumed an ideal obstacle detection system able to identify the opponent vehicle with no restrictions in distance and angle, and able to update this information 100 times a second (i.e. with a refresh rate of 100 Hz). In addition, baseline simulations were also repeated using a more realistic obstacle detection system with the following capabilities: i) a limited cone of view of 60 m long and 90 degrees wide; ii) a refresh rate of 20 Hz; iii) an obstacle detection time of 0.1 s after first detection. With such a system a motorcycle that is travelling towards a fixed object at 50 km/h, would first detect the object at 49.3 m away and then identify the object as an obstacle when it is 47.9 m away. Triggering would not occur before the obstacle is identified.

Data Analysis

Results from the simulations were analysed using descriptive statistics. The timing of MAEB triggering and effects in terms of difference in the impact speed of the host motorcycle due to the system were illustrated using box plots. The upper and lower bounds of the boxes represent respectively the lower and upper quartiles, and the bands in the boxes are the medians. Whiskers indicate the minimum and maximum data within three times the interquartile range from the box extremities. At further distances, data are represented as outliers.

Adopting the Monte Carlo method we assumed that variants are reasonable alternatives to baseline cases in representing the actual crash cases; and that each variant case has the same probability to be the closest representation of the related actual crash case. Therefore, in each crash case the percentage of the simulated variants that involve MAEB triggering represents the likelihood that the system would have triggered had it been fitted on the bike.

RESULTS

According to the experts' opinion, MAEB potentially applies to 22 DCA scenarios. Typical application scenarios include rear end, U-turn, fixed obstacle, and intersection scenarios. (See Table 4 in the Appendix for the full list.)

Following the criteria previously described, we identified 36 motorcycle crash cases for 11 applicable DCA scenarios. The DCA codes included in this analysis represented approximately half (45%) of all cases investigated in the Victorian study. Other applicable scenarios were not represented among the crash cases available for this study. It was not possible to identify the target number of six representative cases for all scenarios. Selected scenarios were well distributed between the three datasets as shown in Figure 1 (13, 12, and 11 cases respectively from MICIMS, NeuRA, and CASR).

If we consider the baseline cases, MAEB triggered in all the cases except one, and produced an absolute reduction in the impact speed of the host motorcycle between 1.0 km/h and 9.9 km/h, with a mean value of 4.2 km/h. The relative impact speed reduction was in the range from 1% to 32% (mean 9%). According to the simulations, MAEB would have triggered in a range of time between 0.23 s and 0.48 s before the actual collision (mean 0.35 s). MAEB was not triggered in one case with a scenario DCA of 111 (vehicle from adjacent directions, right far).

In 18 of the 36 baseline cases (50%), the rider attempted a braking manoeuvre. For the cases involving manual braking of the rider, the mean ISR was 4.4 km/h, while pure autonomous braking in the remaining cases produced a mean ISR of 3.8 km/h. A qualitative analysis of the results shows that when manual braking is involved ISR values are scattered (see Figure 2). This dispersion is due to different timing and decelerations of the braking manoeuvre performed by the rider, which affect the ISR produced by MAEB.

A collision still took place in almost all the randomly generated variants (98% of variants). Variants not resulting in a collision cannot be considered as approximations of the related actual case (which did lead to a collision) and were excluded from the analysis. In 30 crash cases (83% of the sample), MAEB triggered in all the variants leading to a collision. Considering all cases, MAEB triggered in 98% of the total instances involving a collision. In the variants of two crash cases MAEB activation was less than 80%: a case with a DCA of 111 (73% activations) and a case with a DCA of 130 (79% activations). As expected, in the variant simulations MAEB showed a broader range of results than those obtained in the baseline simulations, with an absolute impact speed reduction of up to 13.4 km/h (mean 4.0 km/h) and a relative impact speed reduction of up to 49% (mean 8%). A case by case comparison between baseline and variants' means is shown in Figure 5.

Box plots of the triggering timing and the impact speed reduction of MAEB in the variant cases, grouped according to the crash scenarios, are shown in Figure 3 and Figure 4 respectively.

A comparison of the simulation results obtained assuming ideal obstacle detection technology and those obtained assuming a more realistic obstacle detection technology showed that in 7 cases (20%) there was no decrement of the effects of MAEB. The maximum absolute decrement in the effects of MAEB due to realistic technology (1.4 km/h, 14% decrement) was observed in a case belonging to scenario DCA113; whereas the maximum relative decrement (19%, 0.9 km/h decrement) was observed in scenario DCA121. The latter was the most common DCA code seen in the Victorian cases investigated by the MICIMS study (n=236), corresponding to 15% of crashes. The overall mean decrement of effects due to a realistic technology was 7%. A case by case comparison between ideal and realistic technology in the baseline cases is shown in Figure 5.

DISCUSSION

The first aim of this paper was to assess whether the effects of MAEB estimated for baseline crash reconstructions (i.e. those directly obtained from the in-depth crash reports of some crash investigation studies) can be used to evaluate the effects that MAEB would have had in the real world, had the motorcycle been fitted with such system. To do so, a sample of motorcycle crashes was identified from the three available Australian crash datasets. While this sample is not necessarily representative of the entire crash population, it provides examples of a broad range of crash types for which MAEB may be useful. The simulations of the sample cases confirmed that the effects of MAEB in baseline configurations are a reasonable approximation of the effects that may have been obtained in the actual crashes they refer to. In fact, the impact speed reduction produced by MAEB in baseline simulations was close to the mean impact speed reduction of the associated variants. In particular, the maximum underestimate of the impact speed reduction in a baseline case was 18% of the variants' mean, and only two baseline cases (6% of the sample) overestimated the effects of MAEB by more than 25% compared with associated variants' means effects. These cases were a DCA 110 (cross traffic scenario) with opponent vehicle travelling at 85 km/h, resulting in +97% of ISR in the baseline case, and a DCA 130 (rear

end scenario), resulting in + 43% of ISR in the baseline case. The timing of trajectory convergence in these crash types is indeed more sensitive than other crash types. In particular, in a high speed crossing crash the timing is very sensitive (e.g. even a small delay would mean the collision becomes inevitable only a fraction of second before the actual impact). Similarly, in a rear end crash the offset in location is very sensitive due to the small width of a motorcycle. For these scenarios, accurate estimates of the effects of MAEB can be achieved when the baseline conditions obtained from the crash reconstruction are detailed and reliable.

Concerning the second aim of the paper, it was found that MAEB effects were not strongly affected by the limitations of a more realistic obstacle detection system instead of ideal technology. The reason is that MAEB is typically triggered at a few tenths of a second before the actual collision, as shown in Figure 3. By that time the opponent vehicle had already entered the field of view of the obstacle detection system in most situations, allowing enough time for the system to classify it as a potential obstacle before MAEB triggering.

These two findings suggest that the results of previous evaluations of MAEB effects based on baseline cases and involving ideal obstacle detection can be considered realistic.

Another important aspect of this work is that we have estimated the potential effect of MAEB for a number of distinct crash types. Here we have defined these crash types by DCA code. While the sample of crashes used in this study is not designed to be representative of the population of motorcycle crashes in any particular jurisdiction, they do provide a good range of crashes across these DCA crash type codes. The DCA codes covered here represent about half of all MICIMS cases (45%) and include the 7 most frequent multi-vehicle crashes by DCA code in the MICIMS dataset. While multi-vehicle crash types are clearly over-represented here, they do account for approx. two thirds of all PTW injury crashes. In future work we aim to study the potential of MAEB at a crash population level, where we can estimate the proportion of crashes of specific types (or with particular DCA codes). Using an approach similar to the population-attributable risk fraction (PARF) ([Rothman, Greenland, & Lash, 2008](#)) we hope to eventually be able to estimate the potential effect of MAEB at the population level.

Limitations

A limitation of our approach is that we used two dimensional simulations for each given case and therefore complex dynamics (such as wheel locking, yawing motions, fall events with or without rider separation, etc.) were not considered. However, we believe this approach is suitable for the present study, given the fact that our simulations involved motorcycles travelling straight, and given our focus on overall impact speeds.

Despite confirming previous results showing the applicability of MAEB in real world motorcycle crashes, the major limitation of our approach to estimate MAEB effects is that the parameter we considered (impact speed reduction) cannot be immediately translated into injury reduction effects. A further step that tries to find a translation of impact speed reduction into much more tangible effects for riders is now essential to estimate the benefits of MAEB. That translation is particularly crucial to correctly evaluate the role that MAEB development should have in future road safety strategies.

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Table 1. Descriptive characteristics of the in-depth crash datasets included in the study

	CASR	MICIMS	NeuRA
Period	2009-2013	2012-2014	2012-2013
Number of crashes for the analysis	51	123	80
% Single vehicle crashes	33	34	
% Urban roads	33	69	57.5
% Scooters	2	8	4
% Sports motorcycles	55	27	56
Rider age % <18	0	0	5
% 18-24	16	19	17.5
% 25-34	12	17	34
% >34	69	64	43.5
Severity % Minor injuries (MAIS<2)	20	4	
% Moderate injuries (MAIS 2)	25	44	
% Serious injuries (MAIS=>3)	20	52	
% Fatal	35	0	

Table 2. Rating scale used to evaluate the applicability of MAEB to the crash configurations and their subclasses included in the DCA chart.

Rating	Description	Criteria
1	Would have definitely NOT applied to crashes belonging to this specific scenario	No obstacle / no vehicle; other vehicle hitting PTW from behind; stationary PTW
2	Would possibly have applied (controversial)	Narrow obstacle; PTW on curve / turning; head on collision; other vehicle hitting PTW; side swipe
3	Would probably have applied (technical challenges still need to be solved)	PTW on straight hitting not narrow, moving obstacle
4	Would have applied (typical configuration)	PTW on straight hitting not narrow, fixed obstacle; rear end collision, PTW on straight

Table 3. Parameters and associated standard deviations (with reference to the host motorcycle trajectory) considered in the process of generating variant cases.

Parameter	Standard deviation
Initial speed	6% of baseline value
Lateral position at impact referred to opponent vehicle	0.3 m
Heading at impact	3 deg
Trajectory radius	6% of baseline value
Rider's reaction time	0.3 s
Longitudinal acceleration	0.06 g

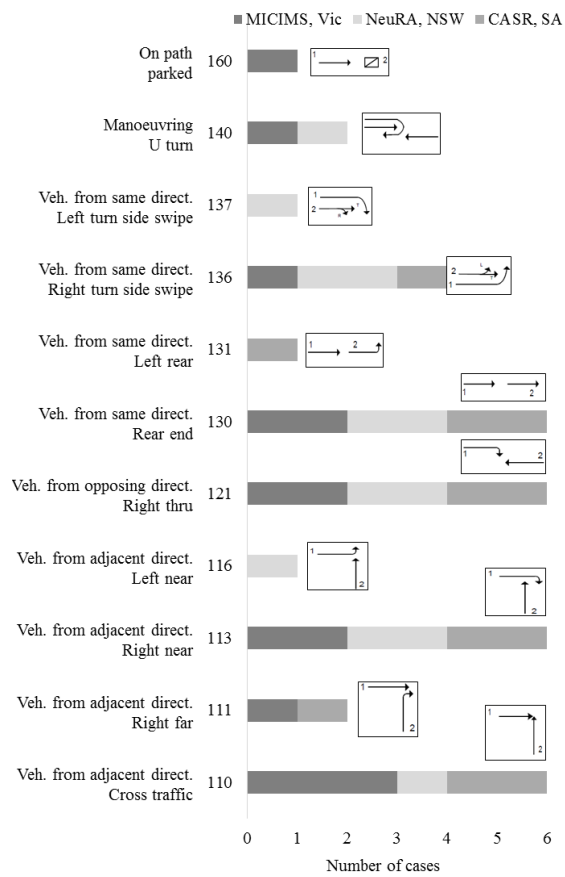


Figure 1. Number of crash cases used in the present study classified by DCA scenario codes and dataset of origin.

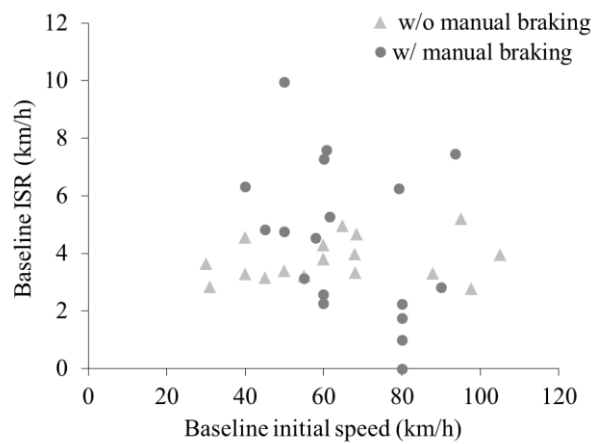


Figure 2. Comparison of the impact speed reduction (ISR) produced by MAEB in the baseline cases involving manual braking and in those without manual braking. Values of ISR are plotted against the initial speed. Each marker represents a single crash case.

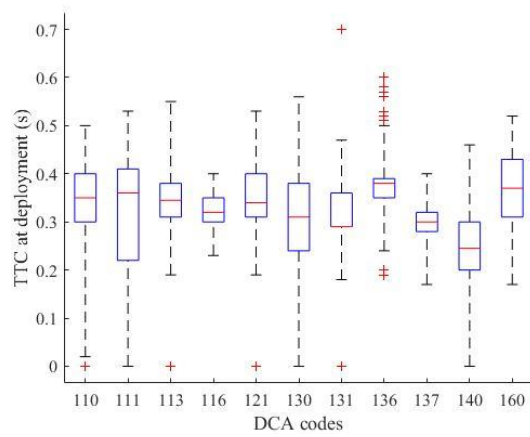


Figure 3. Box plot of the time to collision (TTC) at which MAEB deployed in the simulated variant cases, grouped in crash scenarios according to the DCA code.

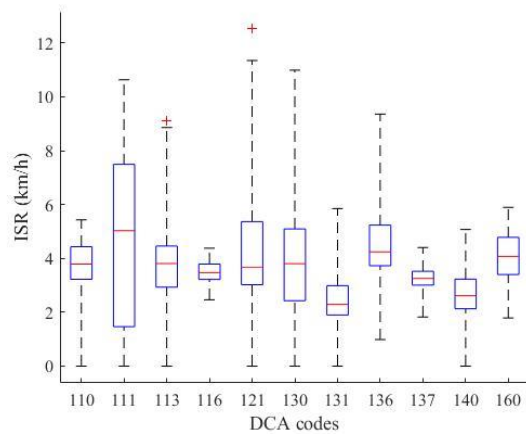


Figure 4. Box plot of the impact speed reduction (ISR) produced by MAEB in the simulated variant cases, grouped in crash scenarios according to the DCA code.

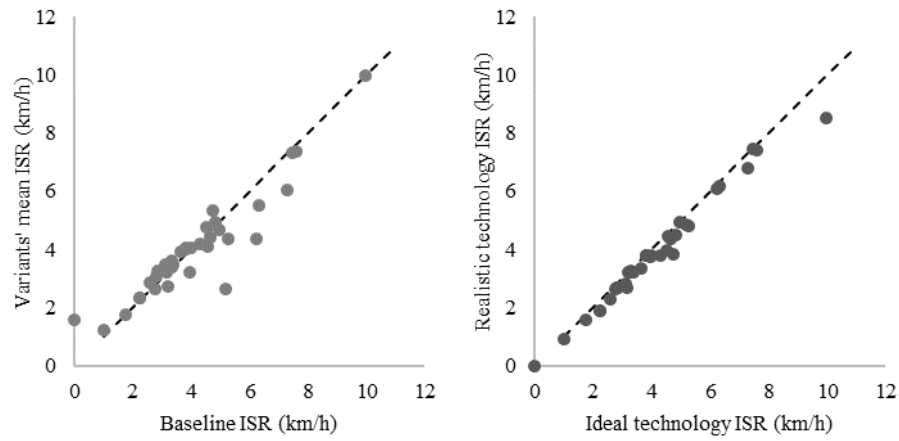
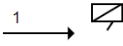
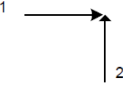
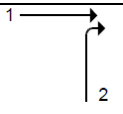
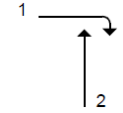
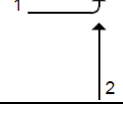
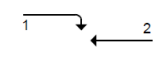
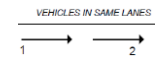
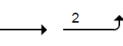
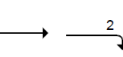

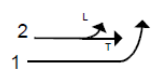
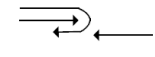
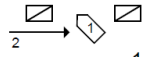
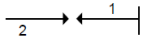
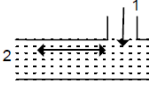
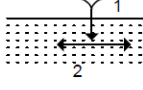
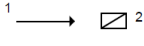
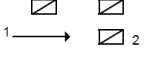
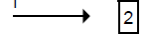
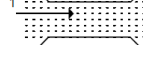
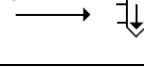
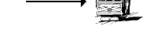


Figure 5. Comparison of the impact speed reduction (ISR) produced by MAEB; each dot represents a single crash case. a) Baseline vs. related variants, both assuming ideal obstacle detection technology; b) ideal technology Vs. realistic technology for obstacle detection, both in the baseline configuration.

APPENDIX

Table 4. List of DCA codes where MAEB was considered applicable by the experts' opinion (ratings 3 and 4).

Type (DCA)	Code (DCA)	Subclass (added)	Description (DCA)	Sketch (DCA)	Config notes (added)	MAEB applic (MODE RATED)
Pedestrian	108		struck while boarding or alighting vehicle			3
Vehicles from adjacent directions	110	A	cross traffic		PTW into other vehicle	3
Vehicles from adjacent directions	111	A	right far		1 PTW into 2 (turning right)	3
Vehicles from adjacent directions	113	C	right near		2 PTW into 1	3
Vehicles from adjacent directions	116	C	left near		2 PTW into 1	3
Vehicles from opposing directions	121	C	right thru		2 PTW into 1	3
Vehicles from same direction	130	A	rear end		1 PTW	4
Vehicles from same direction	131	A	left rear		1 PTW	4
Vehicles from same direction	132	A	right end		1 PTW	4
Vehicles from same direction	136	B	right turn side swipe		2 PTW	3
Vehicles from same direction	137	B	left turn side swipe		2 PTW	3
Manoeuvring	140	C	u turn		1 PTW u turns into other vehicle	3

Manoeuvring	143	B	entering parking		2 PTW	3
Manoeuvring	145	B	reversing		2 PTW	4
Manoeuvring	147		emerging from driveway/lane		1 PTW into 2 or 2 PTW into 1	3
Manoeuvring	148	A	from footway		1 PTW into 2 or 2 PTW into 1	3
On path	160	A	parked		1 PTW	4
On path	161	A	double parked		1 PTW	4
On path	162	A	accident or broken down		1 PTW	4
On path	164		permanent obstruction on carriageway			3
On path	165		temporary roadworks			4
Passenger and miscellaneous	192		struck train			4